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Department of
Electrical & Electronics Engineering

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Major Project Presentation

Design and Fabrication of Hybrid Solar Panel Cleaning Robot

Group No.: G5

Students Name (USN)

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INTRODUCTION

- Due to the continuous depletion in the available conventional energy resources like coal, oil and their harmful effect on the environment, the attention is steered towards utilizing and developing the renewable and sustainable energy sources.
- This growing interest in renewable energy has resulted to significant expansion of the solar Photovoltaic (PV) sector as it is the most common and abundant source of energy.
- PV systems are considered as one of the most widespread solution with significant margins of improvement while ensuring the generation of energy with low environmental impact.

Fig 1.1 - Robot cleaning solar panels

INTRODUCTION

- Around 11.8% of power generated in India is through solar power that reaches to about 53.997 GW (as of 31st March 2021).

- As the country is planning to establish a greater number of solar power generation plants resulting in creating the opportunities to build the sustainable, efficient plants.

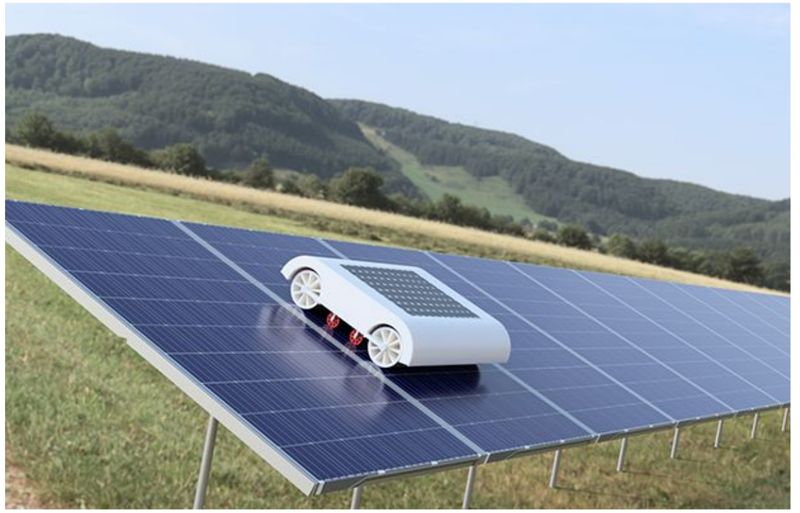


Fig 1.2 - Automated solar panel cleaning robot

- Generally, Solar cells have efficiency around 15-20%. It is much less for modules and the accumulation of dust on the panels decreases the efficiency by considerable amount.

- Considering the same fact, it is essential to maintain the solar power output in optimum value by cleaning the panels regularly.

PROBLEM STATEMENT

“To design and fabricate a solar panel cleaning robot and conduct tests to analyze the performance of the solar panels.”

INNOVATION

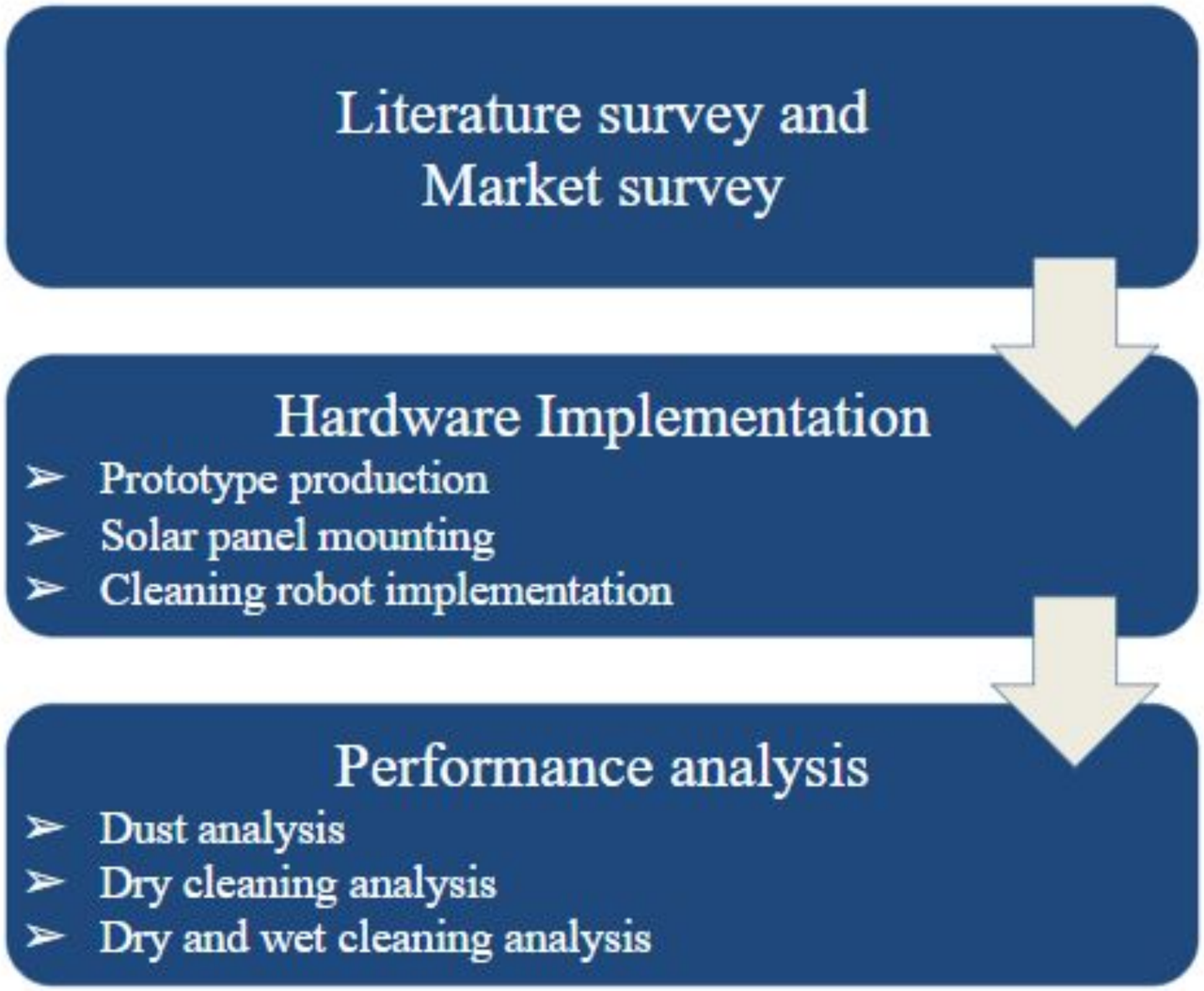
- The robot is a **hybrid model** integrated with **dry cleaning** and **wet cleaning**.
- It is a light weight robot with the maximum weight of **25 Kg**. Solar panels can sustain weight in the range of 100-150 Kg.
- The cost of fabricating the robot is around **Rs 30,000 - Rs 40,000,** which is very less as compared to the models existing in the market.
- It has been designed and integrated in such a way that **all the parts can be easily removed or replaced.**
- **High strength Aluminium grade 6061** has been used to build the frame.

- **Adjustable wheels**
  - Drive wheels can be adjusted based on the height required.
  - Support wheels can the adjusted according to the panel dimensions, in this case the width.
- **Docking station**
  - Helps to reduce the weight of the robot
  - Provide a docking space in unfavourable weather conditions.

OBJECTIVES

- To study the various models of cleaning systems available for solar panels.
- To design a control circuit for the movement of the cleaning robot along the panel and operation of cleaning brushes.
- To implement a prototype for the robot.
- To design and fabricate a hybrid solar panel cleaning robot.
- To perform various studies to check and analyze the performance of the hybrid model on monocrystalline and polycrystalline solar panels.

METHODOLOGY



LITERATURE SURVEY

Sl. No	Authors	Name of Paper	Publication Details	Summary
1	Parrott, Brian & Zanini, Pablo & Shehri, Ali & Kotsovos, Konstantinos & Gereige, Issam. (2018).	Automated, Robotic Dry-Cleaning of Solar Panels in Thuwal, Saudi Arabia using a Silicone Rubber Brush.	Solar Energy, Volume 171, 2018, Pages 526-533	A solar panel dry cleaning robot is introduced which uses a new type of brush which uses silicone rubber foam flaps mounted onto an aluminum core. The efficiency of the cleaning robot is compared to with the efficiency of the currently used used manual cleaning. Additionally, a test was conducted using electroluminescence to investigate the panel quality and assess the potential of damage to them due to the cleaning action.
2	S. K. Thomas, S. Joseph, T. S. Sarrop, S. B. Haris and R. Roopak	Solar Panel Automated Cleaning (SPAC) System	International Conference on Emerging Trends and Innovations In Engineering And Technological Research (ICETIETR), Ernakulam, pp. 1-3, 2018	Experiments were carried out on SPAC System that uses soft yet powerful nylon brushes to clean the panels and also has two sponge on either side of brush to wipe out water. In this system, the water is reused, vibration free, multiple row cleaning.

LITERATURE SURVEY

Sl. No	Authors	Name of Paper	Publication Details	Summary
3	N. Hashim, M. N. Mohammed, R. AL Selvarajan, S. Al-Zubaidi and S. Mohammed.	Study on Solar Panel Cleaning Robot	IEEE International Conference on Automatic Control and Intelligent Systems (I2CACIS), 2019, pp. 56-61	Design and development of an automated cleaning system for a solar based collector to minimize and eliminate the effect of dirts and soiling on the performance of solar systems is discussed. The system monitors the power production and clean the PV surface as soon as it is required in real time using the mobile application.
4	N. Ronnaronglit and N. Maneerat	A Cleaning Robot for Solar Panels	5th International Conference on Engineering, Applied Sciences and Technology (ICEAST), 2019, pp. 1-4	The proposed cleaning robot system uses Ultrasonic Sensors and is energised by using gear motor that can operate at a surface level of 0-30 degrees Celsius. Experiments and testing of the efficiency limitations of solar cells cleaning robots in different conditions and tilt angles are conducted.

LITERATURE SURVEY

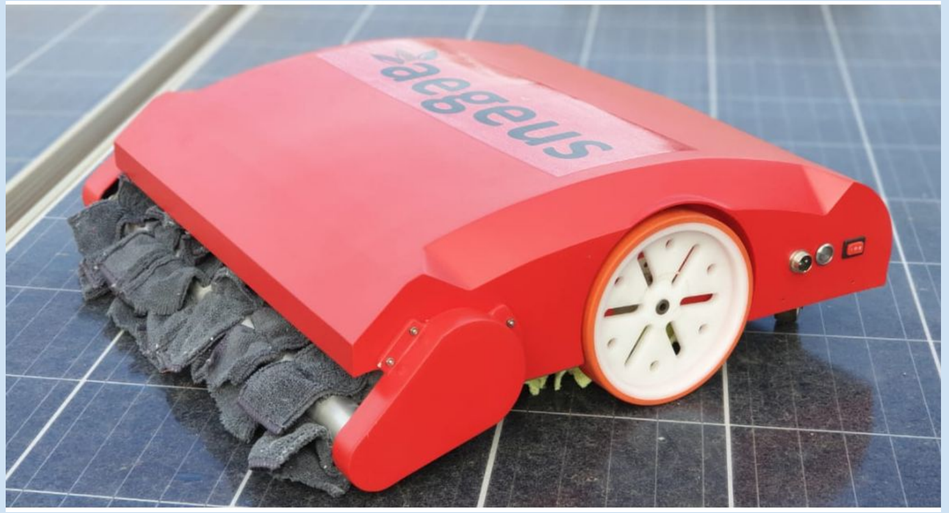
Sl. No	Authors	Name of Paper	Publication Details	Summary
5	S. Santosh Kumar, S. shankar and K. Murthy	Solar Powered PV Panel Cleaning Robot	International Conference on Recent Trends on Electronics, Information, Communication & Technology (RTEICT), 2020, pp. 169-172	A self powered robot is discussed which generates the power required by Solar PV panel mounted on the robot. It is controlled remotely by IoT. The robot periodically cleans PV panel autonomously by blowing air, spraying the liquid and wiping out the dust with wiper and drying the wet content on the panel using cylindrical brush
6	Eltayeb, Wallaaldin & Gandham, Yedukondalu & Srinath. A	Design and Development of a Cleaning Robot for Solar Panels with Sun Tracking	Journal of Green Engineering, Volume-10, Issue-10, October 2020, pp. 9517-9532	The proposed robot cleans solar panels by using a rotary nylon brush with water spray and is integrated with sensors and sun tracking to improve the efficiency of the panel. The cleaning mechanism gets activated when the efficiency or the power output of the panel is low. In standby mode, the robot accumulates electric power in the parking station.

Sl. No	Authors	Name of Paper	Publication Details	Summary
7	Mohammad A. Jaradat, Mohammad Tauseef, Yousuf Altaf, Roba Saab, Hussam Adel, Nadeem Yousuf, Yousef H. Zurigat	A fully portable robot system for cleaning solar panels	10th International Symposium on Mechatronics and its Applications (ISMA), 2015, pp. 1-6	A portable automated system for solar panel cleaning is developed in which a robot is fixed to the solar panel and moves on the panel while cleaning it. It utilizes a dry system of 2 brushes to clean the panels therefore no water is used. After the completion of the cleaning process, the robot is transferred to the next line of panel through a carrier cart which moves on a rail platform.
8	Benatiallah, A. M. Ali, F. Abidi, D. Benatiallah, A. Harrouz and A. Mansouri	Experimental study of dust effect in multi-crystal PV solar module	International Journal of Multidisciplinary Sciences and Engineering (IJMSE), vol.3, no.3, pp.1-4, 2012.	The performance of the solar panels is determined in the desert environment with high irradiance with the introduction of various types of dusts.

MARKET SURVEY

Sl. No.	Product Name & Description
1.	Aegeus Semi-automated robot It is a semi automated cleaning robot which is designed to retrofit in utility scale. It utilizes dry system of cleaning using soft microfibre brushes. There is no need for water or harmful chemicals. The docking station is equipped with a solar panel to charge the Robot batteries when docked. If the batteries are not charged enough, the robot will continue to be in the docking station or it will return to the docking station if it is under operation. 

Sl. No.	Product Name & Description
2.	Aegeus Unicorn It is an IOT/Cloud connected Smart Robot with Machine learning capabilities. It can acquire weather information, if there is rain predicted does not operate. It senses dust levels and cleans accordingly. It can differentiate dust from bird droppings or panel breakage and acts accordingly. It is a self-cleaning and self-powered robot. 

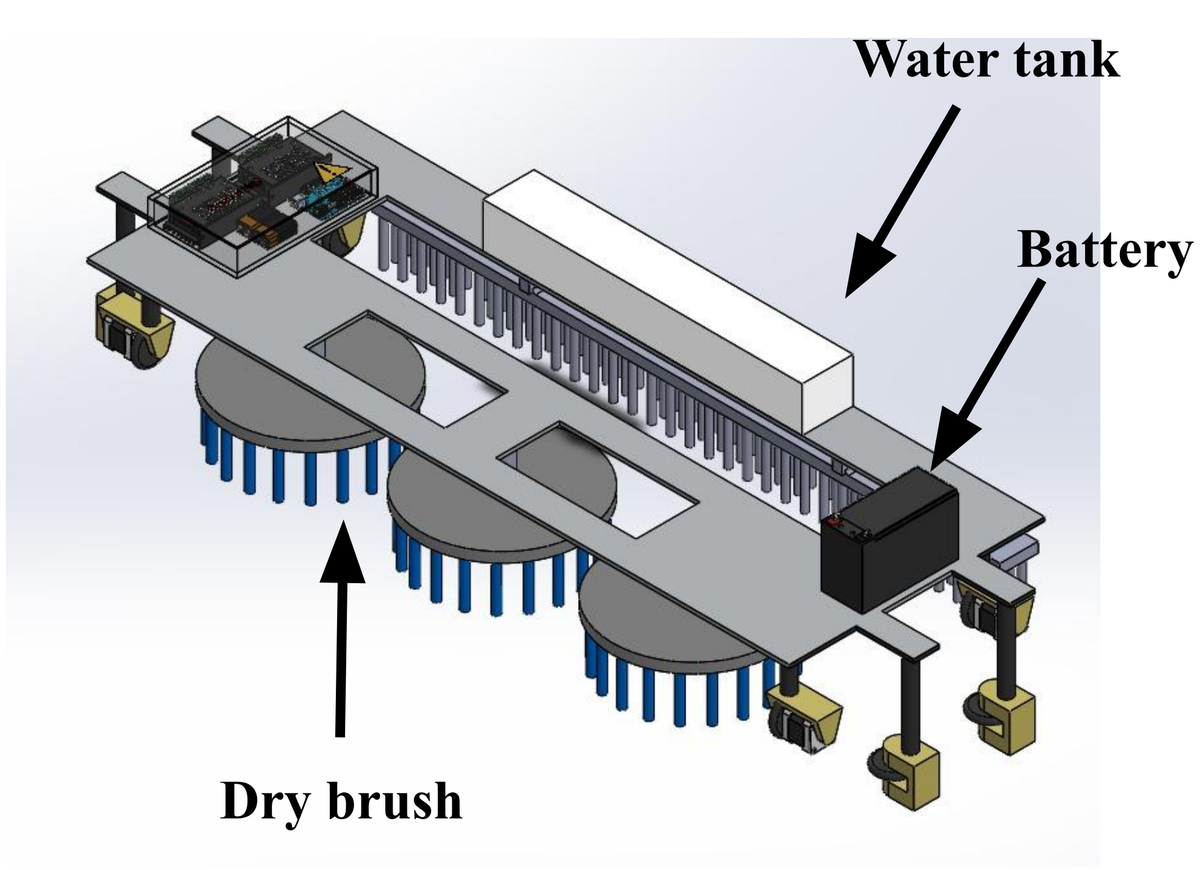
Sl. No.	Product Name & Description
3.	Aegeus Shreem It is used for rooftop solar projects. Its Airwash Technology ensures that there is no need for water or any harmful chemicals. It consists of two sets of soft microfiber cloth brushes (Axial & Radial). Controlled air flow ensures the dust is blown away from the panels efficiently. The Radial brush also ensures it blows away any leftover dust from the edges. It can clean around 200 Panels in an hour and it comes with a backpack so that it can easily be carried from one location to the other. 

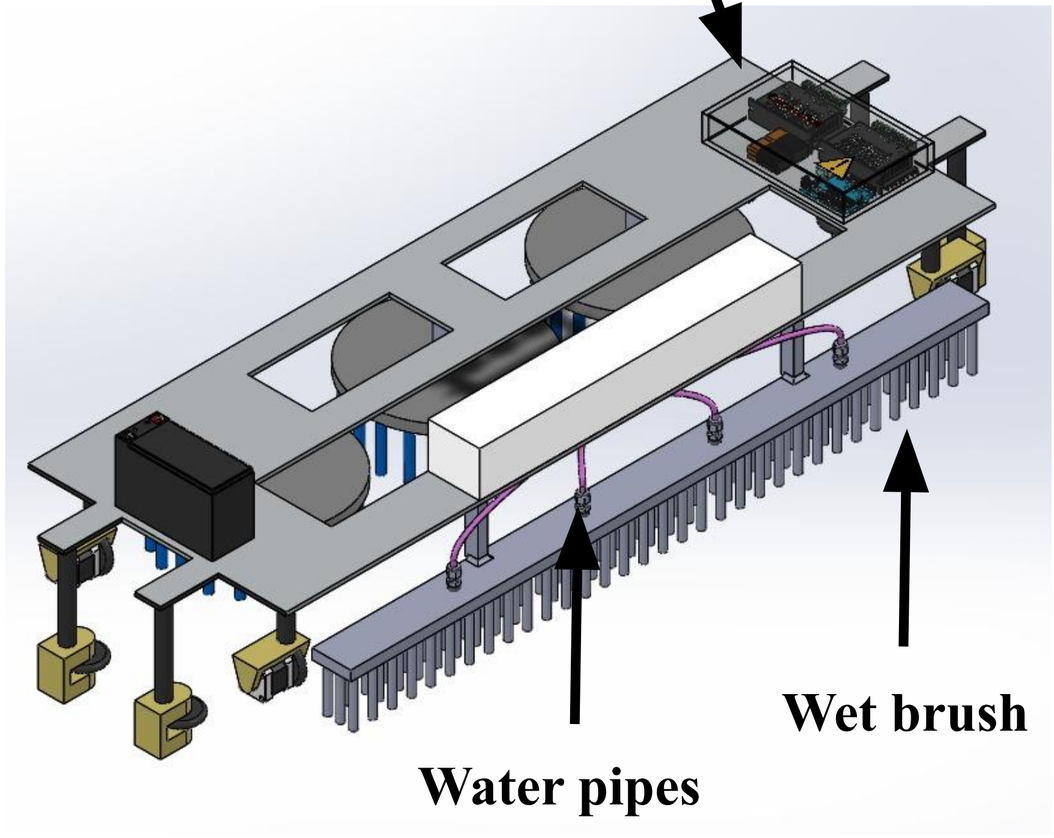
Sl. No.	Product Name & Description
4.	Taypro 2.0 basic It is a fast cleaning waterless solar panel cleaning robot designed to retrofit in utility scale as well as rooftop solar plants which are not designed specifically for robotic cleaning with minor infrastructural modifications. The robot is compatible with fixed tilt, seasonal tilt and horizontal single axis trackers. 

Sl. No.	Product Name & Description
5.	Taypro 2.1 Automatic Taypro 2.1 Automatic is a cleaning robot compatible with any size of solar panel rows and the device comes equipped with a system which allows the robot to overcome high levels of irregularities and undulations. Some of its features include scheduled automatic cleaning, over the air updates, long lasting battery backup, scratch-free technology etc. 

3D MODEL

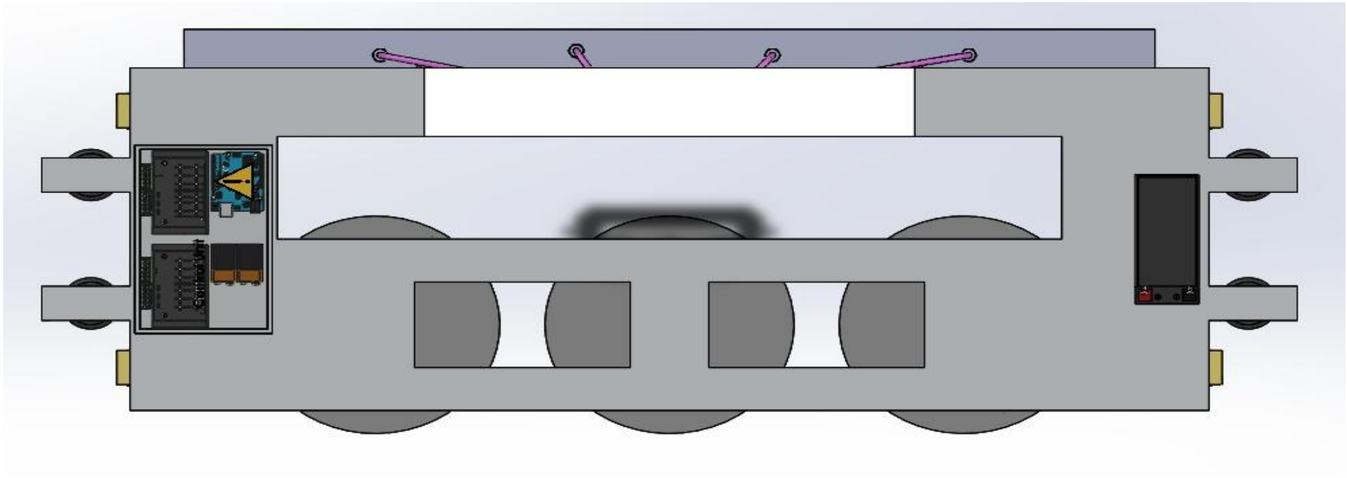
Isometric view:



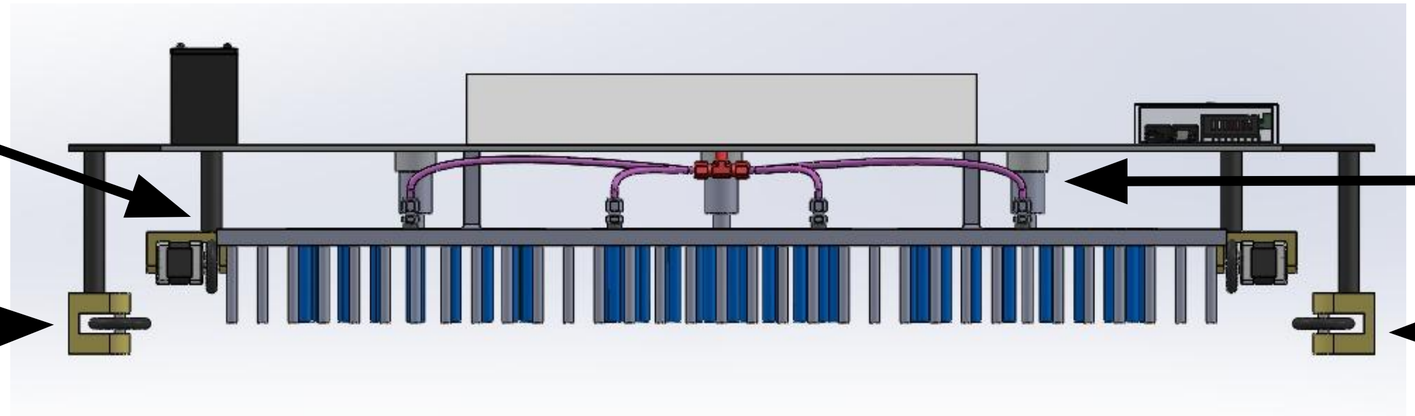


3D MODEL

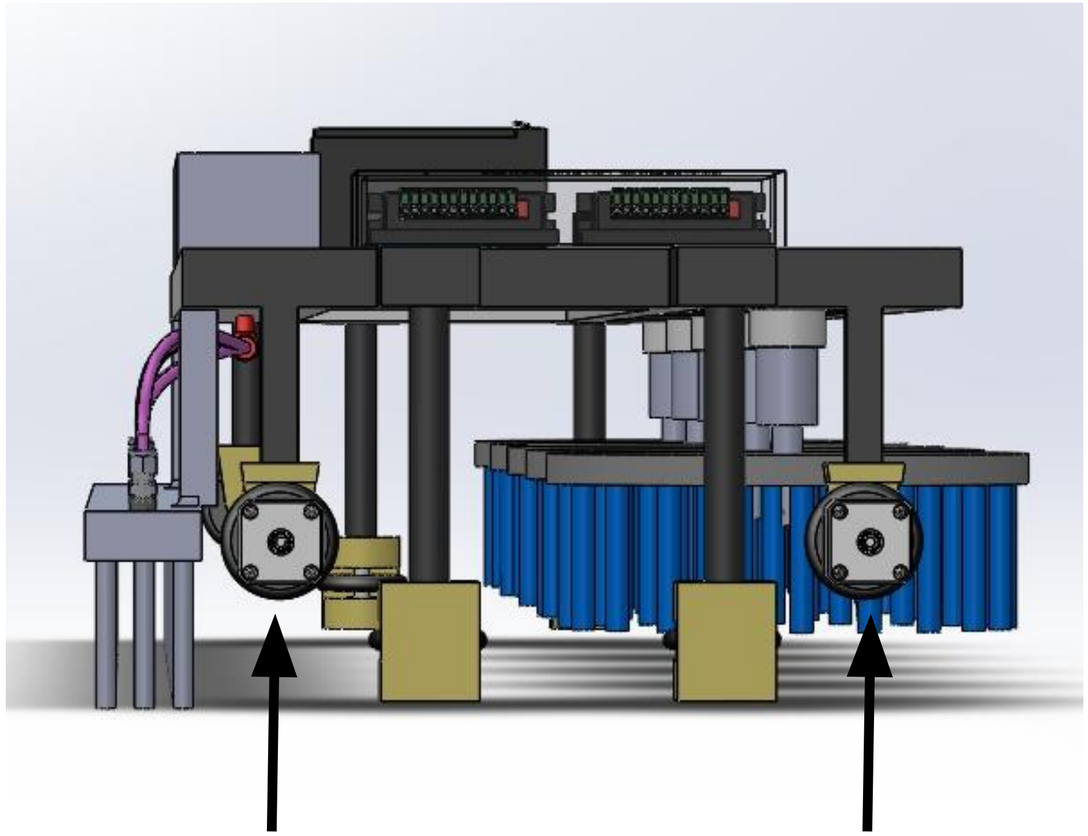
Top View:

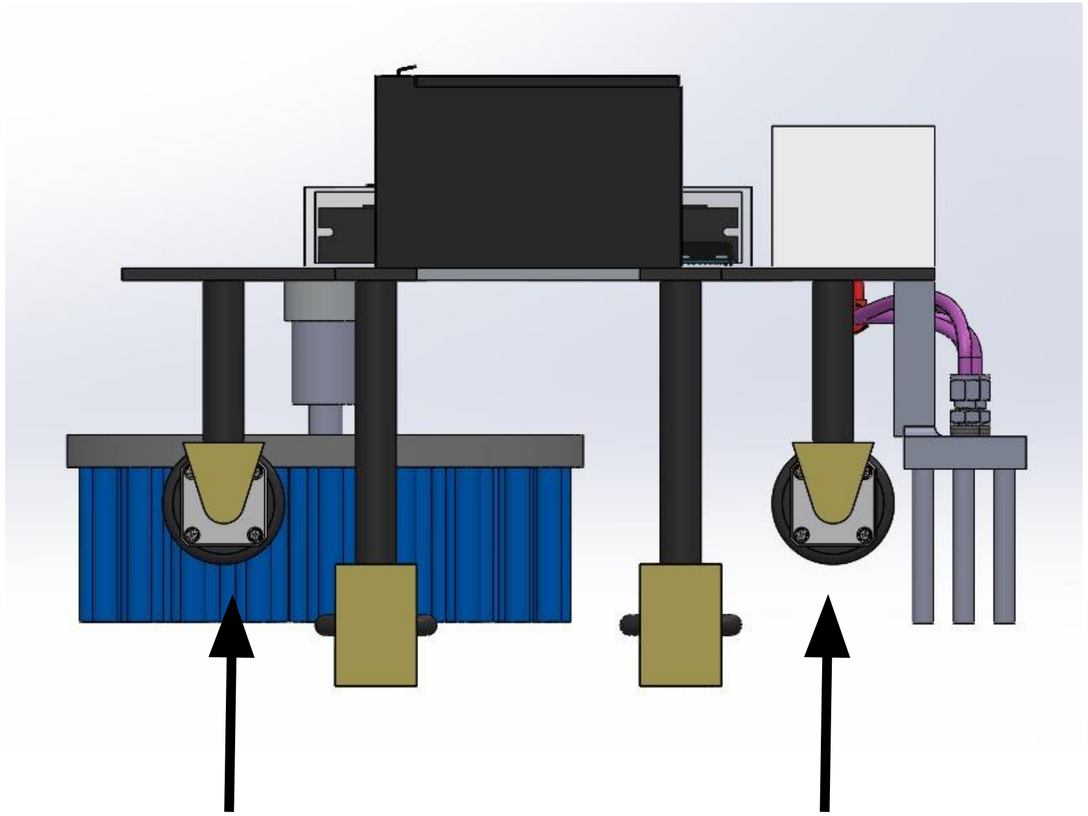


Side view:



3D MODEL





Design of Heavy duty DC geared motor

Ratings of the heavy duty DC geared motors are designed for the required torque and power ratings.

Here, the radius of the wheel is 1.1 cm. Torque and power are calculated using following equations.

- Radius of the shaft = 1.1 cm
- Torque, T = F * r

  = 25 x 1.1 = 27.5 kg-cm (2.69 N-m)
- Power, P = (2π*N*T)/60

  = (2 x 3.14 x 30 x 2.69) / 60 = 8.44 W

Design of Heavy duty DC geared motor

Parameter	Value
Operating voltage	12 V
No load current	220 mA
Load current	1300 mA
No load speed	60 RPM
Rated torque	10 kg-cm
Shaft diameter	8 mm
Motor dimensions	70 x 70 x 90 mm

Design of DC gear motor

Ratings of the DC gear motors are designed for the required torque and power ratings. Here, the radius of the circular brush is 12.7 cm. Torque and power are calculated using following equations.

- Radius of the shaft = 12.7 cm
- Torque, $T = F * r$

  $= 1 \times 12.7 = 12.7$ kg-cm (1.24 N-m)
- Power, $P = (2\pi * N * T)/60$

  $= (2 \times 3.14 \times 350 \times 1.24) / 60 = 45.42$ W

Design of DC gear motor

Parameter	Value
Rated voltage	350 rpm
Operating voltage(Vdc)	6-8 V
Nominal voltage	12 V
Rated torque	2.2 kg-cm
Stall torque	9 kg-cm
No-load current	300 mA
Load current	900 mA
Shaft diameter	6 mm
Motor dimensions	100 x 40 x 40 mm

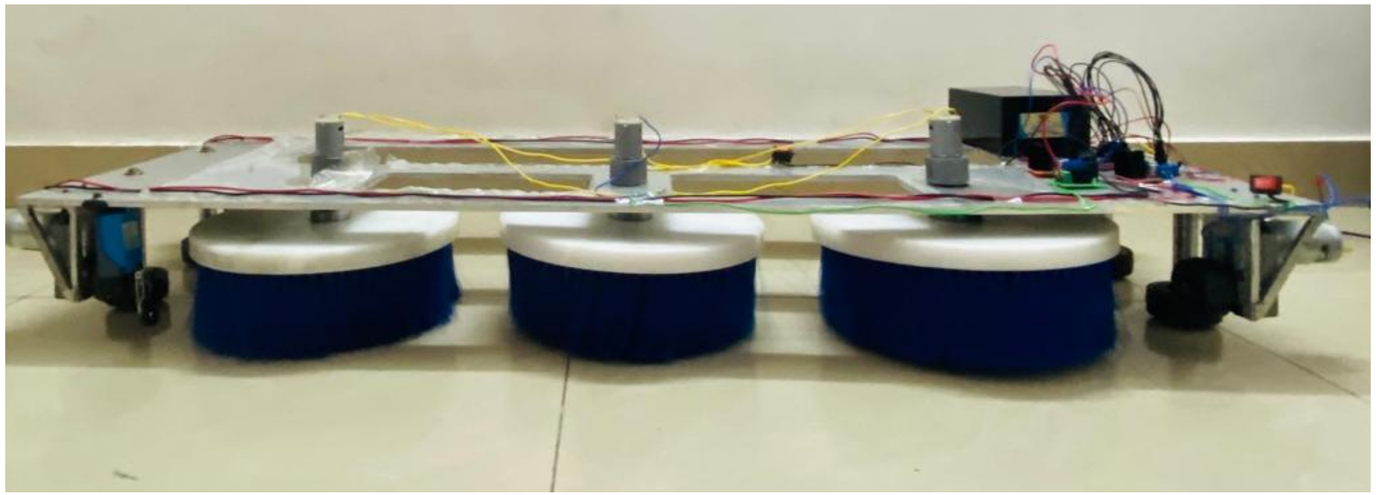
Battery Rating Calculations

The robot has 3 DC geared motors and 4 heavy duty DC geared motors for the operation of brushes and actuation systems. Solar battery that powers the motors is designed and required current capacity is calculated based on the motor ratings. The 12V system is considered for calculation purposes.

- Number of DC gear motors = 3 (each of 45W)
- Total power = 3×45 = 135 W
- Number of heavy duty DC geared motors = 4 (each of 8.5W approx)
- Total power = 4 × 8.5 = 34 W
- For 12 V system, current rating of battery = (135+34)/12 = 14.08 A
- Two 7Ah batteries are needed.

HARDWARE IMPLEMENTATION

Hardware hybrid model:



HARDWARE IMPLEMENTATION

Hardware hybrid model:

Hardware hybrid model:

HARDWARE IMPLEMENTATION

Docking station:

HARDWARE IMPLEMENTATION

Working model video:

Dust analysis:

- IV & PV curve is plotted for both monocrystalline and polycrystalline panels. Fill factor(FF), Maximum power point(MPP) and efficiency is calculated from the graph using the following formulas.

  Fill factor (FF) = (Imp * Vmp)/(Isc * Voc)

  Maximum power point (MPP) = Vmp * Imp

  Efficiency = MPP/ (A*I)

  Where, A is the surface area of the panel in m^2

  I is the irradiance in W/m^2

- Total surface area of polycrystalline panel = 3.257 m^2

  Total surface area of monocrystalline panel = 2.683 m^2

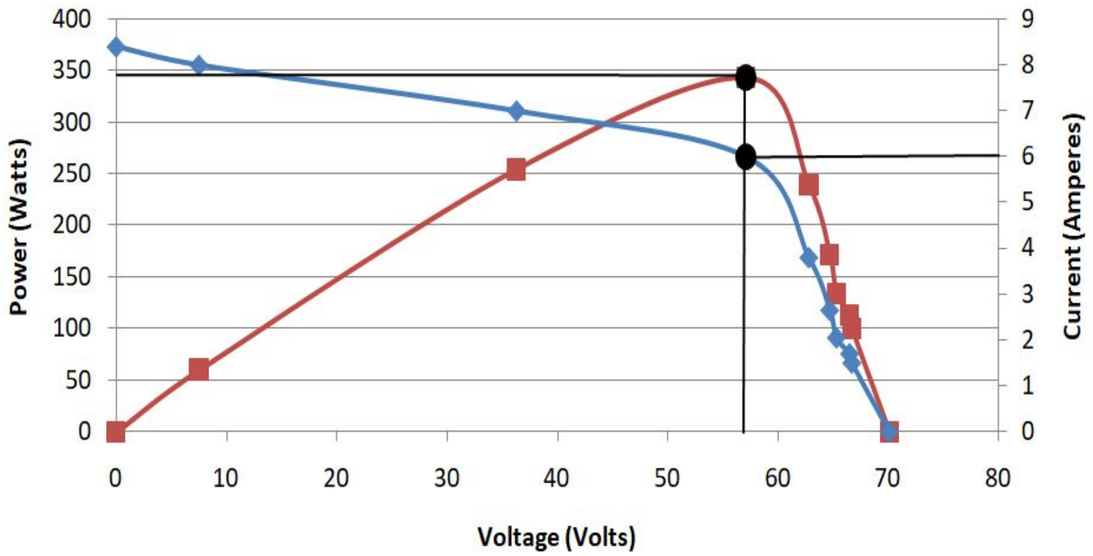
Dust analysis: Day 1

Irradiance = 810.39 W/m^2

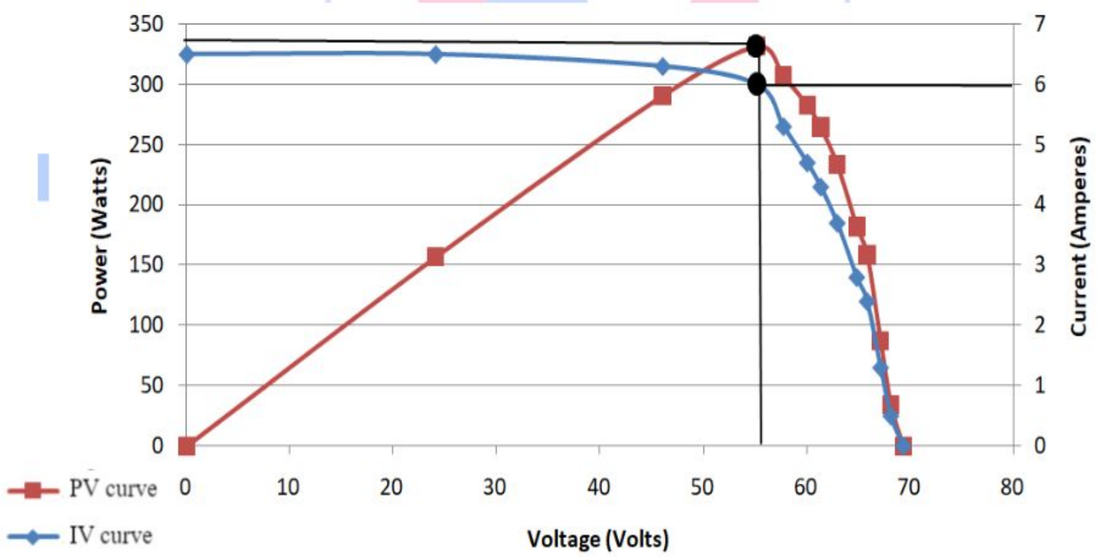
Temperature = 24℃

Efficiency of Monocrystalline panel= 14.32%

Efficiency of Polycrystalline panel= 12.98%



IV & PV curve for Polycrystalline Panel



IV & PV curve for Monocrystalline Panel

Dust analysis:

- Natural soiling on the panels-

RESULTS

The analysis was performed on both the types of panels with a gap of 4 days. The efficiencies for both polycrystalline and monocrystalline panels are given in the table below.

Day	Temperature	Irradiance	Polycrystalline panel efficiency	Monocrystalline panel efficiency
Day 1	24℃	810.39 W/m^2	12.98%	14.32%
Day 5	23℃	798.28 W/m^2	11.77%	13.93%
Day 9	23℃	806.18 W/m^2	10.67%	13.24%

RESULTS

- From the results obtained, it is evident that, as the days progress, there is a drop in the efficiency of the panels due to an increase in the dust accumulation on the panels. The analysis is similar for both the types of panels.
- The efficiency of the panels is also affected by the irradiance and the weather conditions of that particular day.
- Monocrystalline panels are less affected by dust as compared to polycrystalline panels.

Performance analysis:

Comparison of panels before and after cleaning-

Performance analysis:

Performance analysis was conducted for both the panels by artificially soiling the panels with red sand and then cleaning it with the robot. The efficiencies are given in the table below.

Irradiance - 1,01,887 LUX/ 804.9 W/m^2

Temperature - 22℃

Type	Polycrystalline panels	Monocrystalline panels
Efficiency & MPP before cleaning	11.72% 307.28 W	12.49% 269.73 W
Efficiency & MPP after dry cleaning by robot	12.20% 320.09 W	13.71% 296.16 W
Efficiency & MPP after dry and wet cleaning by robot	12.63% 331.18 W	14.05% 303.44 W

RESULTS

- It is observed from the performance analysis that the efficiency of both monocrystalline and polycrystalline panels is improved after cleaning the panels with the robot.
- There is an increase in the maximum power for both monocrystalline and polycrystalline panels.
- The efficiency of monocrystalline panels has increased from **12.49% to 14.05%**.
- The efficiency of polycrystalline panels has increased from **11.72% to 12.63%**.

CONCLUSION

- The efficiency of the panel reduces due to the accumulation of dust. Hence a solar panel cleaning robot has been designed and fabricated.
  - The experimental results of dust analysis show that the effect of dust is more on polycrystalline panels as compared to monocrystalline panel.
  - It is seen that the efficiency of polycrystalline panel reduces from **12.98% to 10.67%** whereas the efficiency of monocrystalline panel reduces from **14.32% to 13.24%**. The drop in efficiency is more in polycrystalline panel than monocrystalline panel.
- As there are three rotating brushes and one rectangular brush for cleaning of the panel, the entire surface of the solar panel is covered while cleaning.

CONCLUSION

- Cleaning the panels with the robot has improved the efficiency of monocrystalline panels from **12.49% to 14.05%** and the efficiency of polycrystalline panels from **11.72% to 12.63%**.
- As a separate docking system is designed on the side of the panel to charge the robot, the overall weight of the cleaning robot is decreased. This reduces the chances of damaging the panel.

FUTURE SCOPE

- The robot can be made lighter if Lithium ion batteries are used but it would increase the cost.
- The intelligent system with application of image processing algorithms can be introduced to estimate the amount of dust on the panel.
- The sound can be reduced by using high quality motors.
- Dust analysis can be performed using current, voltage and dust sensors and the real time data can be analyzed through cloud.

REFERENCES

1. M. Surajit, M. Amit Kumar, A. Sharma, V. Devalla, S. Rana, S. Kumar and J. K. Pandey, “An overview of cleaning and prevention processes for enhancing efficiency of solar photovoltaic panels”, Current Science Journal, vol. 115, no. 6, pp. 65-77, September 2018. DOI: 10.18520/cs/v115/i6/1065-1077.

2. Benatiallah, A. M. Ali, F. Abidi, D. Benatiallah, A. Harrouz and A. Mansouri, “Experimental study of dust effect in multi-crystal PV solar module”, International Journal of Multidisciplinary Sciences and Engineering (IJMSE), vol.3, no.3, pp.1-4, January 2012. DOI: 10.4324/9781315074405-84.

3. M.R Kiran and R.G Padaki, “Self-Cleaning Technology for solar PV Panel”, International Journal Of Scientific Development and Research (IJSDR), Volume 1, Issue 9, May 2016, pp. 8-16. DOI: 10.1109/IJSDR.2018.8393812.

4. S. K. Thomas, S. Joseph, T. S. Sarrop, S. B. Haris and R. Roopak, "Solar Panel Automated Cleaning (SPAC) System", International Conference on Emerging Trends and Innovations In Engineering And Technological Research (ICETIETR), Ernakulam, pp. 1-3, 2018. DOI: 10.13140/RG.2.2.12286.64322

5. A.Gheitasi, A. Almaliky and N. Albaqawi, "Development of an automatic cleaning system for photovoltaic plants”, IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), Brisbane, QLD, pp. 1-4, 2015. DOI: 10.1109/APPEEC.2009.4918029

REFERENCES

6. M. A. Jaradat , "A fully portable robot system for cleaning solar panels", 10th International Symposium on Mechatronics and its Applications (ISMA), Sharjah, pp. 1-6, 2015. DOI: 10.1109/ISMA.2015.7373479

7. Q. Zhang, X. Lu and J. Hu, "A solar panel cleaning system based on a linear piezoelectric actuator", Symposium on Piezoelectricity, Acoustic Waves, and Device Applications, Changsha, pp. 1-4, October 2013. DOI: 10.1016/j.energy.2013.07.058

8. T. Sorndach, N. Pudchuen and P. Srisungsitthisunti, "Rooftop Solar Panel Cleaning Robot Using Omni Wheels", 2nd International Conference on Engineering Innovation (ICEI), Bangkok, pp. 7-12, 2018. DOI: 10.1109/ICEI18.2018.8448530.

9. G. Aravind, G. Vasan, T. S. B. G. Kumar, R. N. Balaji and G. S. Ilango, "A Control Strategy for an Autonomous Robotic Vacuum Cleaner for Solar Panels", Texas Instruments India Educators' Conference (TIIEC), Bangalore, pp. 53-61, 2014. DOI: 10.1109/TIIEC.2014.018.

Thank you